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(54) **Forming braze-bonded abrasive turbine blade tip**

(57) In a preferred embodiment, a nickel base superalloy turbine blade tip is coated with an abrasive for wear-forming a seal track in a gas turbine engine by gluing a self-sustaining preform comprising abrasive alumina grit and nickel-base superalloy braze powder onto the tip and heating to melt the superalloy and braze the grit to the tip. The preferred grit is titanium coated to strengthen bonding between the alumina and the braze alloy. The abrasive grit may also be a carbide.

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SPECIFICATION

Method for forming braze-bonded abrasive turbine blade tip

This invention relates to an abrasive coating applied to a gas turbine blade tip for wear forming a seal track in a stationary shroud. More particularly, this invention relates to a method for coating a turbine blade tip with a preformed abrasive grit to the tip using a composite preform.

In a gas turbine engine, gas flow between a tip of a rotating blade and a cooperating stationary shroud reduces efficiency and power. It is therefore desired to minimize clearance between the tip and the shroud to seal against gas flow. One method for accomplishing this is to employ an abrasive grit coating on one or more blade tips of a rotor to wear-form a seal track in the shroud. The coatings comprise grit mechanically held, for example, in an electroplated metal matrix. A major problem with this method is that the grit tends to spall during turbine operations. Also, nickel-base superalloy is preferred for blade use but contains a plurality or minor constituents and is not suited for plating. Thus the coating and the blade are composed of different metals. Furthermore, a method is desired that is more suitable for mass production and provides more uniform thickness and grit distribution.

Therefore, it is an object of this invention to provide an improved method for coating a turbine blade with an abrasive for wear-forming a seal track in a cooperating shroud within a gas turbine engine, which abrasive comprises refractory grit tightly bonded within a braze metal matrix to resist spalling.

More particularly, it is an object of this invention to provide a method for coating a superalloy turbine blade tip with abrasive grit braze-bonded within a superalloy matrix having substantially the composition of the blade superalloy. The method not only tightly bonds the grit within the superalloy matrix, but also forms an integral braze bond between the coating superalloy and the blade superalloy. In one aspect of this invention, the grit is coated prior to brazing with a metallic braze-wetting agent, preferably titanium, that forms a strond metallurgical bond between the grit and the coating superalloy.

It is a further object of this invention to provide an improved method for readily applying a spall-resistant, abrasive grit coating to a turbine blade tip, which method is adapted for commercial production. The method comprises brazing a grit-containing preform to the tip. The grit concentration and thickness is readily controlled in the preform to produce a uniform composition and thickness in the coating. An additional feature of this invention is that the preform is readily sized and shaped to produce a coating having a desired pattern.

In a preferred embodiment of the invention, these and other objects are accomplished by forming a sheet comprising abrasive alumina grit and nickel-base superalloy braze powder and employing the preform sheet to braze the grit to a tip surface of a nickel-base superalloy turbine blade. The alumina grit particles have a titanium coating that improves braze-wetting and substantially strengthens bonding between the alumina and braze alloy. Approximately equal volume portions of the grit and a nickel-base superalloy braze powder are slurried with a vaporizable liquid organic cement and spread into a uniform layer. After the cement sets, the layer forms a self-sustaining sheet that is suitably cut and glued onto a turbine blade tip. The blade tip and attached preform are slowly heated to vaporize the cement and thereafter to melt the braze alloy, whereupon the melt forms a continuous phase surrounding the grit and wetting the blade tip. Upon solidification, the grit is entrapped in a superalloy matrix that is integrally braze bonded to the blade tip, thereby forming a spall-resistant abrasive coating.

In a preferred coating of the invention, the metal matrix not only mechanically holds the grit, but it is also believed that the titanium on the grit interacts with the alumina and the braze superalloy to produce a strong metallurgical bond therebetween. The superalloy portion of the coating is integrally bonded to the superalloy of the blade and has substantially the same composition. The use of a braze-grit composite preform results in uniform grit distribution and thickness in the coating. In addition, the preform is readily shaped to produce a desired coating pattern. Furthermore, the use of the preform and operations such as gluing and brazing are well suited for production.

In accordance with a preferred embodiment of this invention, an abrasive coating is applied to a gas turbine engine blade cast of a nickel-base superalloy. The preferred alloy consists of, by weight, 10 percent tungsten, 10 percent cobalt, 9 percent chromium, 5.5 percent aluminium, 1.5 percent tantalum, 1.5 percent titanium, 1.0 percent hafnium, 0.02 percent boron, 2.5 percent molybdenum, 0.15 percent carbon, 0.05 percent zirconium and the balance nickel and is commercially available under the trade designation MAR M247. A preferred blade extends radially from a hub having a center axis about which it is adapted to rotate within a gas turbine engine. The blade comprises a tip remote from the hub and having a substantially flat, axially parallel surface that is intended to lie proximate to a stationary shroud surface in the engine and to be coated with abrasive to wear-form a seal track in the shroud. The coating is suitably applied to an individually cast blade tip prior to assembly in a hub.

Alternately, the coating may be applied to one or more blade tips of an integrally cast rotor. In a surprising aspect of this invention, it has been found that coatings may be simultaneously brazed to blades diametrically arranged on a hub without sagging.

A preferred abrasive grit consists of alumina Al_2O_3 particles sized to about 100 mesh. The particles are coated with a metallic titanium film by vapor deposition. About 100 parts by weight alumina grit are blended with about 10 parts fine titanium hydride powder. The titanium hydride powder is sized to -325 mesh. The mixture is placed in a refractory alumina crucible and covered with a refractory perforated blanket suitable to contain the powders while allowing gases to escape. The covered crucible is then slowly heated in a vacuum furnace evacuated to a pressure less than about 5×10^{-4} torr (666.61 Pa $\times 10^{-4}$). At about 400°C, the titanium hydride decomposes to form hydrogen gas and metallic titanium. A slow heating rate is desired to allow the hydrogen to escape from the crucible without disrupting the powder. After the hydride is decomposed, the temperature is increased to about 1250°C, whereat titanium vaporizes and is deposited onto nearby grit surfaces. The titanium film impoves wetting of the surface by a nickel-base superalloy braze melt. It is also believed that the titanium interacts with the braze alloy and the alumina to form a strong metallurgical bond.

The titanium-coated grit is then mixed with approximately an equal volume of finer braze alloy powder sized to -140 mesh. The preferred braze alloy consists of, by weight, 10.8 percent tungsten, 10 percent cobalt, 9.7 percent chromium, 5.5 percent aluminium, 3.1 percent tantalum, 2.5 percent silicon, 1.6 percent titanium, 1.4 percent hafnium, 1.1 percent boron, 0.6 percent molybdenum, 0.17 percent carbon, 0.05 percent zirconium and the balance nickel. This alloy is essentially similar to MAR M247, but is modified to adapt the alloy for brazing, particularly by relatively high additions of silicon and boron that reduce the liquidus temperature and improve melt flow properties.

The mixture of grit and braze alloy powder is then formed into a self-sustaining sheet. The mixture is slurried with solvent-base vaporizable acrylic cement commercially available from Wall Colmonoy Corporation under the trade designation Nicrobraz.® The cement is of a type particularly formulated as a vehicle for bonding braze powder to metal surfaces in typical metal-metal brazing operations. A minimum volume of cement sufficient to form a pourable slurry is added to the powder.

The slurry is poured onto a sheet formed of a non-stick polytetrafluoroethylene material and covered with a similar sheet. The sandwich assembly is rolled to spread the slurry into a layer having a uniform thickness of about 1.5 millimeters. After rolling, the cover sheet is peeled away to expose the slurry layer to the air for drying. After the cement has sufficiently set so that the layer is self-sustaining, the bottom sheet is peeled away to further aid drying. Drying for about one hour at room temperature is generally adequate. The dried sheet is self-sustaining and suitable for forming an abrasive coating. However, an acrylic lacquer may be sprayed onto the sheet surfaces to prevent cracking and to stiffen the sheet for convenient handling.

The grit-braze sheet is cut using an abrasive silicon carbide wheel into a size and shape corresponding to a desired pattern of the abrasive coating on the blade tip. The preform is then glued onto the blade tip with a cyanoacrylate adhesive. Any hangover is trimmed by grinding. A liquid stop-off alumina oxide slurry is painted onto the sides of the blade adjacent the tip to prevent brazing there.

Brazing is carried out in a vacuum furnace. An individual blade is typically vertically oriented with the preform-bearing tip up. However, it has been found that brazing is also suitably carried out when a blade is oriented horizontally, without the preform falling off upon heating or the coating sagging, even though the tip surface is vertically oriented. Thus, two or more blades of an assembled or integrally cast rotor may be simultaneously coated by this invention.

The furnace is evacuated to less than 10^{-5} torr (133.322×10^{-5}Pa) and initially slowly heated to vaporize the acrylic cement and cyanoacrylate glue. Thereafter, the temperature is raised to about 1230°C and held for about 10 to 20 minutes to melt the braze alloy. Upon melting, the braze alloy forms a liquid phase surrounding the alumina grit and wetting the blade tip. The melt wets and reacts with the titanium-coated alumina particle surface in a manner that produces a strong bond upon cooling. After the braze powder has wet the grit surfaces and the blade tip, the temperature is cooled to about 1090°C for five to ten minutes to set the alloy to prevent sagging or flowing. Thereafter, the temperature is raised to about 1150°C for 20 to 60 minutes. During this time, elements added to modify the superalloy for brazing, particularly boron and silicon, diffuse into the blade and become substantially uniformly distributed in the coating and the cast blade near the tip. This diffusion raises the liquidus temperature of the coatings to a level suitable for turbine engine operations.

The product coated tip comprises alumina grit tightly held within a nickel-base superalloy matrix, which matrix is tightly brazed to the cast superalloy of the blade. Superalloy in the coating and in the blade has substantially the same composition, particularly after diffusion

during brazing. Within the coating, the proportion of grit to alloy is essentially the same as formulated in the preform. Also, uniform coating thickness is obtained, particularly for coatings on different blades of a rotor. If necessary, the coating may be ground to true up the blade dimensions or provide a desired contour. In addition, the surface of the coating may be chemically or electrochemically etched to better expose the grit to improve initial abrasiveness.

In the preferred embodiment, titanium is coated onto the grit to produce a strong metallurgical bond between the alumina and the braze alloy. It is believed that titanium deposited in immediate contact with the alumina surface bonds to oxygen in the alumina, essentially becoming part of the oxide structure. Titanium that is deposited further away remains substantially metallic. Because of its metallic nature, the titanium coming in contact with the braze melt improves wetting and itself alloys with the nickel-base superalloy. Thus, both the alumina-titanium interface and the titanium-superalloy interface are strengthened by chemical bonding so that the overall grit-superalloy bond is stronger than mere mechanical joining. While titanium is preferably deposited onto the grit prior to mixing with the braze powder, improved bonding may also be obtained by including titanium hydride powder with uncoated grit and braze powder in a preform sheet, although titanium deposition is less efficient. Other metals, such as hafnium and zirconium, are also suitable for forming hydride-derived coatings that produce similar alumina-superalloy metallurgical bonds.

Other known abrasive oxides, carbides or nitrides may be substituted for the preferred alumina grit, including, for example, titania, zirconia or chromium carbide. The coating preferably comprises about equal portions of alumina grit and superalloy. At least about 30 percent by volume superalloy is believed necessary to adequately bond the grit particles into a cohesive coating. Coatings having greater than about 70 percent by volume alloy do not have adequate abrasive properties.

Although this invention has been described in terms of certain embodiments thereof, it is not intended to be limited to the above description, but rather only to the extent set forth in the claims that follow.

CLAIMS

1. A method for coating a superalloy substrate with an abrasive comprising attaching a self-sustaining preform to the substrate, said preform comprising abrasive refractory grit and superalloy braze powder cohesively bonded together by a vaporizable organic adhesive, heating the preform to vaporize the adhesive and to melt the braze powder to form a braze liquid phase surrounding the grit and wetting the substrate, and cooling the substrate to solidify the braze phase to entrap the grit within a superalloy matrix and to bond the matrix to the substrate.

2. A method for coating a superalloy substrate with an abrasive according to claim 1, in which the superalloy substrate is a nickel-base superalloy substrate, the self-sustaining preform is glued to the substrate and comprises abrasive grit and braze powder, said grit comprising refractory particles bearing a braze-wettable metallic coating, and said braze powder comprising a nickel-base superalloy similar to the substrate but having a reduced liquidus temperature for brazing, and the braze superalloy melts on heating to form a continuous superalloy liquid phase surrounding and wetting the grit particles and wetting the substrate.

3. A method for applying to a nickel-base superalloy gas turbine blade tip an abrasive coating of the type employed for wear-forming a seal track within a gas turbine engine, said method comprising gluing to the blade tip a self-sustaining preform comprising abrasive grit and braze powder, said grit comprising alumina particles having a braze-wettable titanium coating suitable for metallurgically bonding alumina to nickel-base superalloy, said braze powder consisting essentially of a nickel-base superalloy similar to the blade tip but having a reduced liquidus temperature for brazing, said preform further comprising a vaporizable organic cement bonding the grit and the braze powder together, slowly heating the preform to vapourize the cement and thereafter to melt the braze superalloy to form a continuous superalloy liquid phase wetting the blade tip and surrounding the grit particles and wetting titanium-coated surfaces thereof, and cooling the substrate to solidify the braze superalloy to form an abrasive coating comprising alumina grit enclosed within and metallurgically bonded to a nickel-base superalloy matrix and to braze bond the braze superalloy to the blade tip.

4. A method for applying an abrasive coating to a nickel-base superalloy substrate according to claim 2 or 3, which includes the steps of slurrying a mixture comprising abrasive refractory grit and nickel-base superalloy braze powder in a liquid comprising a vaporizable organic adhesive dissolved in a vaporizable solvent, said adhesive being vaporizable at relatively higher temperature than said solvent and being present in an amount sufficient to cohesively bond the grit-braze mixture together, then spreading the slurry into a sheet and evaporating the solvent therefrom so as to bond the mixture into a self-sustaining sheet, from which sheet said preform is cut.

5. A method for applying an abrasive coating to a nickel-base superalloy substrate according to claim 2, which comprises heat-

ing a mixture comprising abrasive alumina grit and a metal hydride in a vacuum to decompose the metal hydride and to deposit nascent metal onto the grit, said metal being suitable for forming a superalloy braze-wettable deposit on alumina surface, mixing the metal-coated grit with nickel-base superalloy braze powder and a liquid comprising a relatively high temperature vaporizable organic cement dissolved in a relatively low temperature vaporizable solvent, said liquid being in an amount sufficient to form a spreadable slurry and containing sufficient cement to cohesively bond the grit and the braze powder together, spreading the braze-grit slurry to a desired thickness, evaporating the solvent from the slurry to bond the grit and the braze powder into a self-sustaining sheet, gluing the sheet to the substrate, heating the sheet and substrate to vaporize the cement and to melt the braze alloy to form a braze liquid phase that wets the substrate and surrounds the grit, wetting metal coated surfaces thereof, and cooling the substrate and braze liquid overlayer to solidify the braze liquid to form an abrasive coating comprising grit within a nickel-base superalloy matrix tightly bonded to the substrate.

6. A method according to claim 3, for applying to a nickel-base superalloy gas turbine blade tip an abrasive coating of the type employed for wear forming a seal track within a gas turbine engine, said method comprising heating a mixture comprising abrasive alumina grit and titanium hydride in a vacuum for a time and at a temperature sufficient to decompose the hydride and to deposit nascent titanium onto the grit surfaces to form a braze-wettable film adapted for metallurgically bonding alumina and nickel-base superalloy, mixing the titanium-coated grit with approximately an equal volume portion of a braze powder consisting essentially of a nickel-base superalloy similar to the blade tip but containing boron and silicon in sufficient amounts to reduce the liquidus temperature for brazing, slurrying the grit-braze mixture in a liquid comprising an organic cement dissolved in a solvent, said solvent being vaporizable at ordinary temperatures to set the cement, said cement being vaporizable at elevated temperatures and being present in an aount sufficient to cohesively bond the grit-braze mixture together, spreading the slurry to a desired thickness, evaporating the solvent therefrom to set the cement to form a self-sustaining sheet composed of the the grit and the braze powder, cutting the sheet to form a preform having a desired size and shape for forming the blade tip coating, gluing the preform to the blade tip, heating the glued preform and blade tip to vaporize the cement and thereafter to melt the braze alloy to form a braze liquid wetting the blade tip and surrounding the grit, wetting the titanium-coated surfaces, cooling the blade tip and braze liquid to solidify the braze superalloy to metallurgically bond the grit within a nickel-base superalloy matrix and to braze bond the superalloy matrix to the turbine blade tip, thereby forming an abrasive coating on the blade tip, and heating the coated blade at a temperature and for a time sufficient to diffuse boron and silicon from the superalloy matrix into the blade so as to produce a substantially uniform superalloy composition.

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